# Enhancing Confidence in the Nation's Nuclear

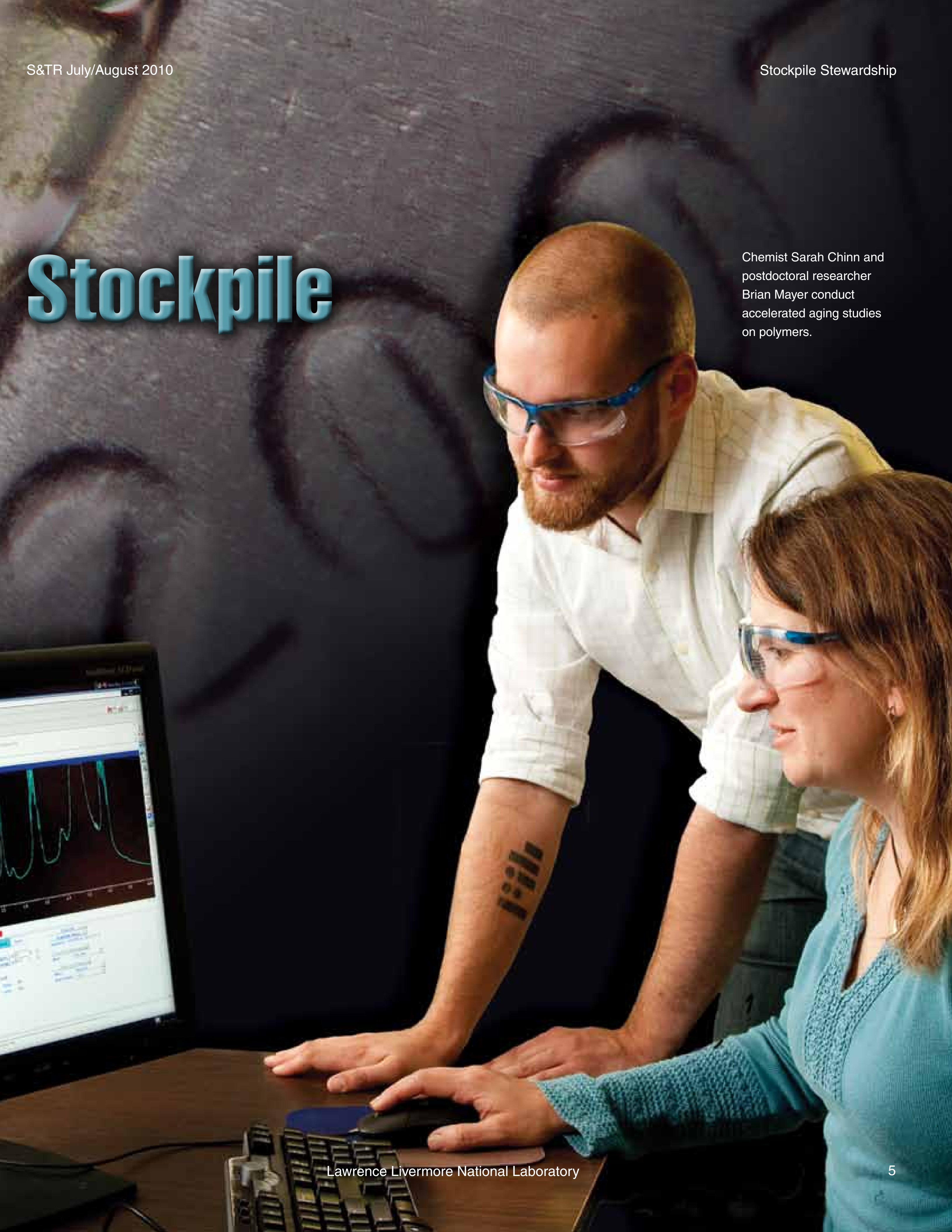
*Livermore researchers combine materials research, experiments, and advanced numerical models to anticipate any problems in America's aging nuclear weapons.*

SOME experts compare the National Nuclear Security Administration's (NNSA's) mission to maintain and enhance the safety and security of America's nuclear stockpile with the National Aeronautics and Space Administration's mission to safely land a human on the moon. The comparison is often made because nuclear weapons are extremely complex devices, with thousands of components that must work together seamlessly to produce a nuclear detonation. What's more, since 1992, scientists can no longer check the performance of nuclear weapons by detonating them underground at the Nevada Test Site. (See the box on p. 6.)

Nuclear weapon components are made of various materials such as high explosives (HEs), steel, plutonium, uranium, and polymers (plastics). Scientists have found age-related changes in some of the components and materials in weapons removed from the stockpile and disassembled. These changes are occurring, in part, because many weapons have been in the stockpile longer than originally intended. Plastics can break down and give off potentially destructive gases, metals can corrode and weaken, and coatings can deteriorate. Some materials may change properties unpredictably in response to the high radiation fields, fluctuating temperatures, and other environments to which nuclear weapons are subject.

In the absence of developing new nuclear weapons, experts must work to extend the life of existing units and understand how their constituent materials and components age. Scientists conduct a comprehensive program of weapon surveillance (close examination), laboratory experiments, and maintenance and refurbishment of components. Data from all activities are used to refine computational models, some of which serve as electronic surrogates for underground testing. These combined activities, which require the efforts of

# Stockpile



Chemist Sarah Chinn and postdoctoral researcher Brian Mayer conduct accelerated aging studies on polymers.

chemists, materials scientists, engineers, physicists, and computer scientists, are called stockpile stewardship. The Stockpile Stewardship Program has been enormously successful to date and has permitted the directors of Lawrence Livermore, Los Alamos, and Sandia national laboratories to annually assess the status of the stockpile and conclude that currently a need does not exist for nuclear testing.

Livermore chemist Bob Maxwell notes that relying solely on routine surveillance of nuclear weapons provides little insight into possible future changes in materials and components that could affect safety or performance. "Inspecting or testing components doesn't help us predict beyond today," he says. "For example, a test of HE material taken from a stockpiled unit may tell us the material is capable of detonating this month but does not necessarily give us confidence in its performance a decade from now."

To gain added confidence, Livermore experts lead numerous efforts in NNSA's Enhanced Surveillance Campaign, aimed at producing informed estimates about how nuclear weapon materials and components will likely change over the next one to two decades. Results from enhanced surveillance efforts are fundamental to life-extension programs, which entail refurbishing or replacing parts to extend the time that a specific weapon system can safely and reliably remain in the stockpile. "We must look 15 to 20 years in the future because it can take that long to fix a problem, given the current lean nuclear weapons infrastructure," explains Bill McLean, manager of Livermore's Enhanced Surveillance Campaign.

For several years, a key thrust of enhanced surveillance centered on studying the properties and aging of plutonium pits found in every modern nuclear weapon. In 2006, the two NNSA nuclear design laboratories—Lawrence Livermore and Los Alamos—issued a joint report stating that "subtle age-induced changes in the atomic structure and composition of plutonium do not, in themselves, limit the lifetime of U.S. weapon pits," and "the majority of plutonium pits for most nuclear weapons have minimum lifetimes of at least 85 years." That finding has permitted Livermore stockpile stewards to shift the focus of their attention to obtaining a better scientific understanding of how other weapon materials and components age and interact during the decades they remain in the stockpile.

Some Livermore enhanced surveillance experiments artificially age materials and components by subjecting them to high temperatures or intense gamma or neutron radiation. Other efforts focus on developing new diagnostics and nondestructive tests. Data obtained from

## Managing the Nation's Ever-Shrinking Nuclear Arsenal

The nation's current nuclear stockpile consists of sea-based, land-based, and air-carried systems. For decades, the performance of the complex nuclear explosive package as well as the nonnuclear components in these weapon systems was confirmed with underground tests conducted at the Nevada Test Site. Since the nuclear test moratorium was adopted in 1992, the U.S. has deployed no new weapons, while thousands of existing weapons have been retired or dismantled.

Under the 2002 Moscow Treaty on Strategic Offensive Reductions, the U.S. has been reducing the number of its operationally deployed nuclear weapons to between 1,700 and 2,200 by 2012. In April 2010, U.S. President Barack Obama and Russian President Dmitry Medvedev signed a new arms reduction pact that pledges to reduce the number of operationally deployed, strategic nuclear weapons in both countries and commits the nations to adopt new procedures for verifying which weapons each country possesses. Under this treaty, called New START, both countries will be limited to 1,550 ready-to-use, long-range nuclear weapons. In the future, as the number of U.S. weapons shrinks, fewer weapons will be available for disassembly, underscoring the importance of nondestructive testing of existing weapons and science-based studies of materials and components.

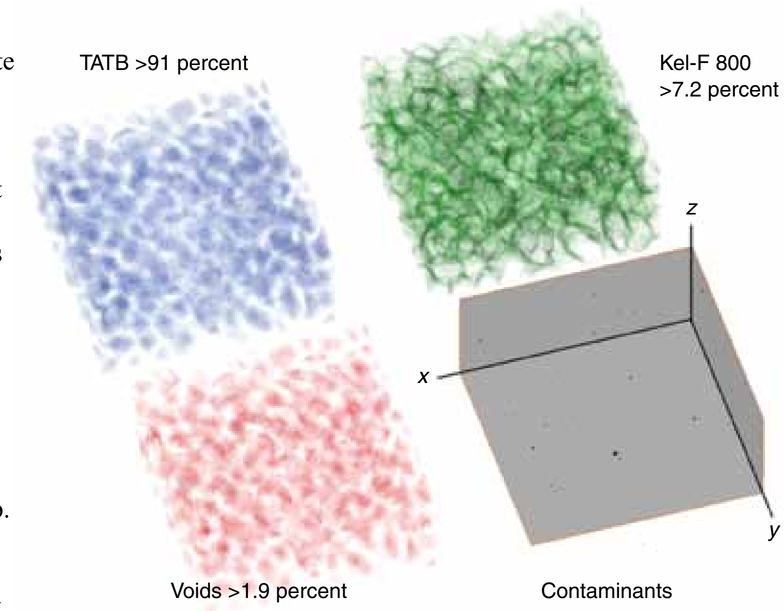
The New START force reductions are a key step in implementing the Obama administration's strategy to reduce nuclear dangers, which is described in the 2010 Nuclear Posture Review (NPR). NPR emphasizes as one of its five major findings the need for the nation to sustain a safe, secure, and effective nuclear arsenal as long as nuclear weapons exist.

Stockpile stewardship is a responsibility of the National Nuclear Security Administration (NNSA), which was established by Congress in 2000 as a semi-autonomous agency within the Department of Energy. The Stockpile Stewardship Program includes science and engineering experiments and computer simulations to study the mechanisms of how nuclear weapon components age. NNSA assesses each nuclear weapon to detect or anticipate potential problems that may come about as a result of aging. As part of that effort, each weapon receives routine maintenance and surveillance (a thorough examination). In addition, the agency extends nuclear warhead lifetimes through the refurbishment of critical components and safely dismantles and disposes of units that have been retired.

NNSA nuclear weapons laboratories—Los Alamos, Lawrence Livermore, and Sandia—assess the health of the current stockpile, design the components and systems for the life-extension programs, and certify the life-extended models when they enter the stockpile. Over the past decade, NNSA has funded new experimental capabilities at the laboratories, including the National Ignition Facility at Livermore and the Dual-Axis Radiographic Hydrodynamic Test Facility at Los Alamos. One of the most far-reaching efforts was instituting the program now known as Advanced Simulation and Computing, which permits the computational "testing" of components and entire systems, and which has impelled a transformation of the nation's supercomputing industry.

enhanced surveillance are used to validate and refine computational models that identify any problems long before they could affect safety or performance. By elucidating the mechanisms of aging—at times, on the atomic scale—the models can also help determine the likely effects of substituting different materials.

"Our goal is to increase confidence in the stockpile, reduce uncertainties about weapon systems, and save taxpayers money in the process," says chemist Pat Allen. He notes that the Livermore work straddles basic materials science and applied science for stockpile stewardship. Allen points to important Livermore advances over the past few years, including a new technique for measuring HE detonations, miniaturized sensors, improved corrosion models, and better methods for measuring polymer gases. These advances could not have been made without the fundamental scientific research conducted over the course of many years at Livermore.




A three-dimensional computed tomography scan of the insensitive high explosive LX-17 reveals the concentration of triaminotrinitrobenzene (TATB), the binder polymer Kel-F 800, and other constituents. The data provide input to codes modeling shock response and detonation.

## High Explosives Set Things Off

One critical enhanced surveillance effort is directed at understanding in greater detail how aging affects the complicated detonation of the chemical HEs that are used to implode the plutonium pit in modern nuclear weapons. Scientists are concerned that, with age, HE components could lose some of their safety and performance features. Experts investigate the physical, chemical, detonation, and mechanical properties of HE taken from the stockpile, such as with the use of radiography to measure the size and density of microscopic grains. They also ensure adequate reserves exist of triaminotrinitrobenzene, an insensitive HE (meaning it is highly unlikely to explode in the event of an accident). (See *S&TR*, June 2009, pp. 4–10.)

Researchers artificially age HE samples and detonation systems with high temperature and radiation. They then look for changes such as cracks and swelling. "These studies give us an opportunity to observe in a relatively short time the same kinds of changes produced over decades in a weapon," says engineer Constantine Hrousis. The studies also provide the data used to improve and validate models of aging HE developed by chemist Rick Gee.

Hrousis and his team are studying the aging of particular components that make possible the complicated event sequence involved in initiating the detonation of the main HE charge, which must properly explode and precisely squeeze the plutonium pit. Initiation systems are first triggered by a burst of current that explodes a small piece of metal, which then ignites a booster charge of HE to set off the main HE charge.

The Livermore-designed W87 warhead, deployed on U.S. intercontinental ballistic missiles, uses a mechanical arming device that features a small pellet of high-density HE, which is kept "out of line" for added safety. On command, the mechanical system moves the pellet into an orientation that permits the HE detonation process to begin. Enhanced surveillance creates tools for tracking these devices, enabling prolonged confidence in their reliable performance and ensured safety despite the fact that they are aging. Computational models are created to accurately simulate the arming and initiation functions of such devices, providing a virtual test bed for aging scenarios and their potential impact on performance and safety.

To extract more information from HE detonation tests conducted at NNSA's Pantex Plant near Amarillo, Texas, chemist George Overturf is overseeing the adoption of a diagnostic tool using photonic Doppler velocimetry (PDV). (See *S&TR*, July/August 2004, pp. 23–25.) Developed several years ago by Livermore physicist Ted Strand, PDV is allowing engineer Michael Gresshoff to measure the particle velocity at the HE outer surface resulting from the detonation, which can reach speeds exceeding 3 kilometers per second.

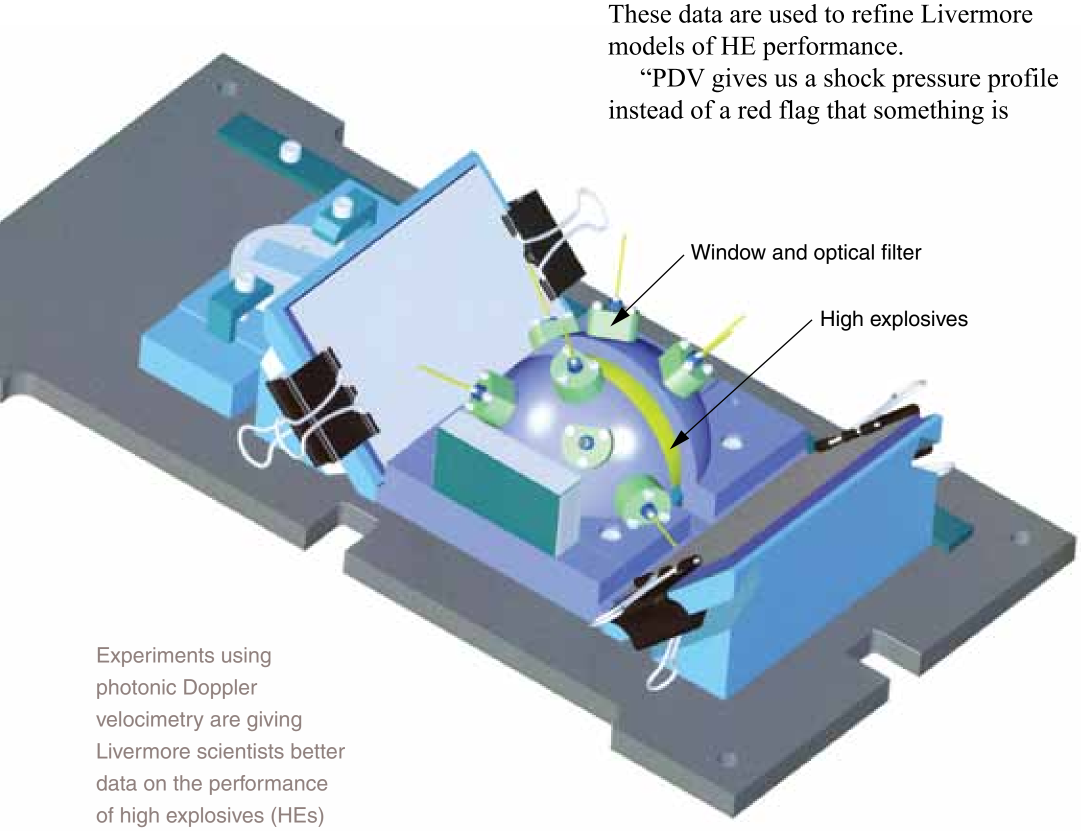
The technique currently used at Pantex, where warheads are disassembled and inspected, involves machining HE into a snowball shape and covering its outer hemispherical surface with a light-enhancing coating for capture by a streak camera. The value of this technique is limited because it cannot determine the completeness of detonation or the strength of the shock.

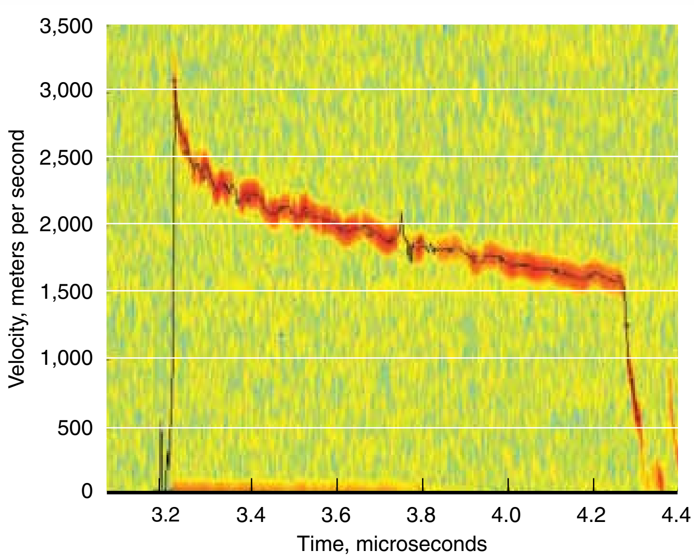
Instead, PDV focuses 1,550-nanometer-wavelength laser light onto the snowball through a fixture with eight clear windows that are in direct contact with the outer insensitive HE surface. During detonation, a detector senses the reflected laser light.

A portion of the original light is also sent to the detector. The difference in frequency between the two light sources is related to the speed at which the outer HE surface is traveling.

This technique provides a significant improvement in data characterizing the HE detonation. PDV measures the detonation particle velocity, which in turn yields the explosive pressure as well as the arrival time (or general shape of the detonation). These data are used to refine Livermore models of HE performance.

"PDV gives us a shock pressure profile instead of a red flag that something is amiss in the detonation," says Overturf. "We're going back to first principles to determine performance." The technique is now undergoing final tests for routine use at Pantex.




Experiments using photonic Doppler velocimetry are giving Livermore scientists better data on the performance of high explosives (HEs) contained in nuclear weapons. (above) HE is machined into a sphere about 62 millimeters in diameter and covered with an aluminum fixture that features eight windows (one is not visible from this view) through which laser light is focused using an optical fiber. (right) When HE is detonated, the particle velocity is recorded over time. From these data, exact pressures can be derived and used to refine models.

### Tiny Sensors Report All

In another effort, researchers are developing a suite of tiny, rugged sensors that could be embedded inside every nuclear weapon to report on the health of critical components as well as on the external environment. The embedded sensors would relay information, perhaps through a USB-like port, whenever scientists deem it necessary. The sensors would thus make possible for the first time "persistent surveillance," that is, continuous monitoring of a weapon's state of health.

About a dozen sensors per weapon would monitor mechanical changes, internal gas composition, and the external environment. The sensors would most likely be emplaced during a weapon system's life-extension program. Sensors also could be added to so-called shelf units stored at NNSA's Y-12 Plant in Tennessee and at Pantex, where individual components identical to those in deployed weapons are monitored for unexpected physical and chemical changes. Once in place, the sensors could be checked to determine if unwanted gases or microscopic cracks and voids are present, and whether a weapon incurs stresses as it is moved.

Sensor experts at the Laboratory are collaborating with scientists throughout the NNSA complex and Britain's Atomic Weapons Establishment. Livermore's Laboratory Directed Research and Development Program funded much of the original proof-of-principle research. Says engineer Jim McCarrick, "We've taken the most promising designs and are developing and testing them."

Stress sensors would be based on microelectromechanical systems technology to measure forces, pressures, and accelerations that components experience. Gas-detecting sensors would combine infrared absorption and Raman scattering to take "fingerprints" of all gases inside the weapon. Both techniques measure how molecular bonds respond to a beam of infrared light generated by a laser and passed through an optical fiber. (See *S&TR*, July/August 2008, pp. 12–19.)

Also under development are sensors to monitor gaps in the relative positions of components to ensure that no parts have moved as well as sensors to look for tiny cracks in parts. Another type of sensor would measure and record a weapon's external temperature and shock history. With this device, scientists could possibly relate a mechanical change to a particular event (such as transporting the warhead) and thereby determine if a detected mechanical change was specific to that weapon or evidence of a systemic problem.

Livermore mechanical engineer Jack Kotovsky designed this tiny contact stress sensor (shown on a dime for scale) for monitoring weapons in the stockpile. The 60-micrometer-thick sensor can repeatedly measure changing loads perpendicular to a surface within a weapon system.

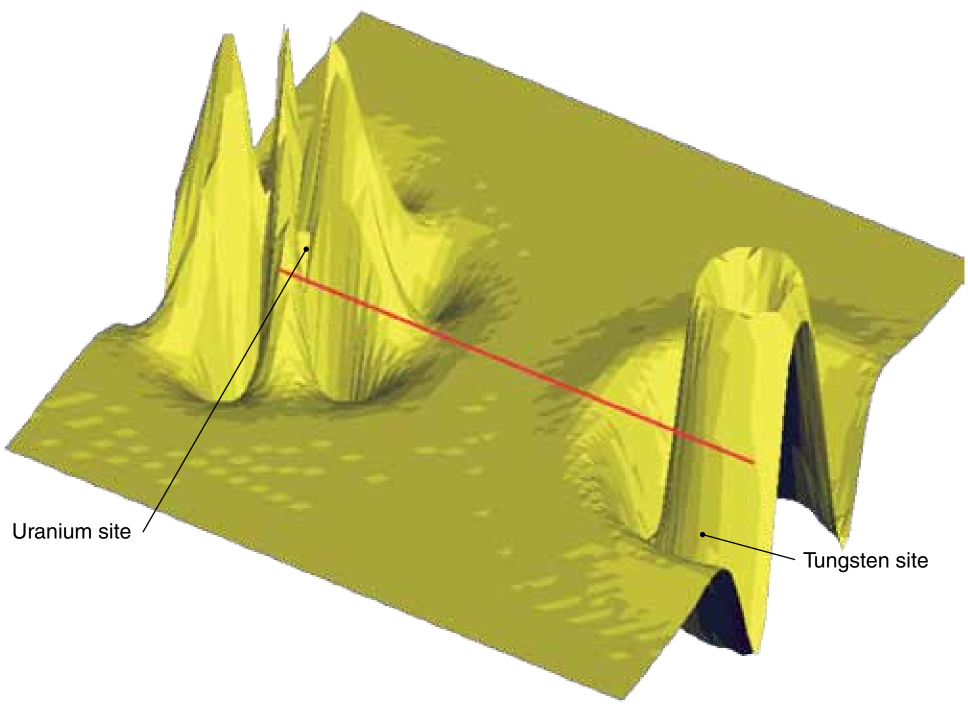
## Modeling Corrosion from Hydrogen

Another enhanced surveillance effort is refining models that simulate uranium aging with unprecedented fidelity. Chemist Tyzh-Chiang Sun notes that uranium is virtually "pristine" when it is inserted into a nuclear device. The nuclear explosives package is then sealed with inert gases. However, within a few years, internal conditions can become corrosive from the liberation of simple compounds, especially hydrogen.

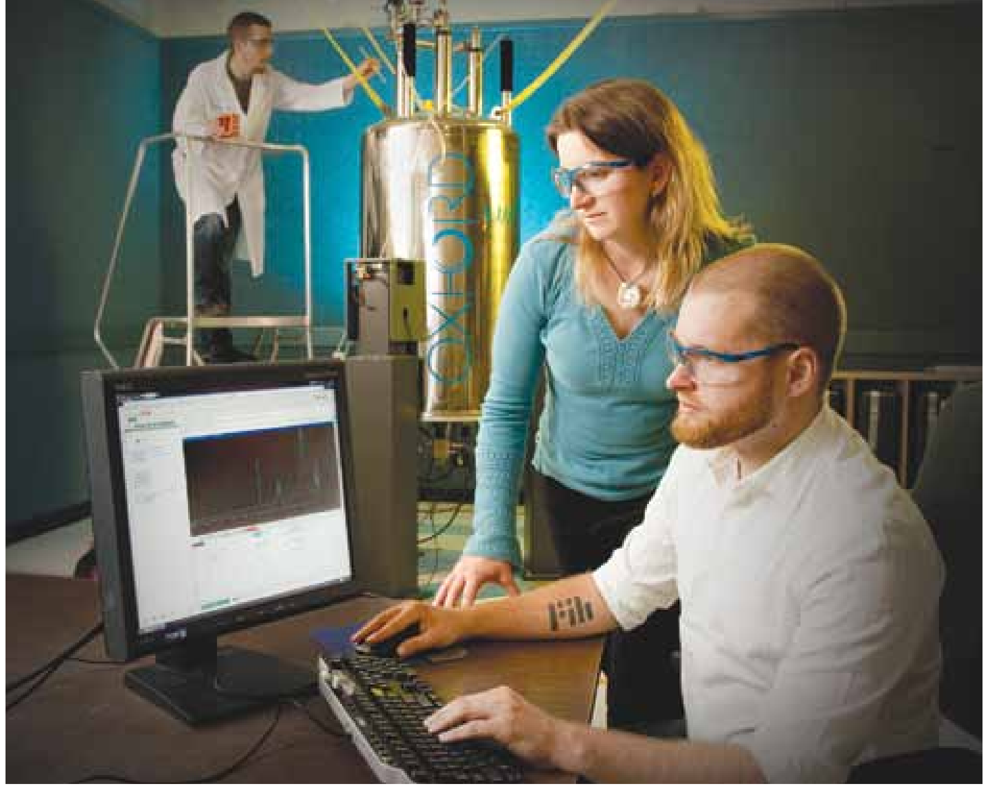
Warhead components can give off hydrogen directly, or they can react with a small amount of water vapor to form intermediate compounds that liberate hydrogen. Once in contact with uranium, hydrogen forms uranium hydrides, corrosion products that could potentially affect weapon performance.

Hydrogen corrosion can take years, even decades, to cause a problem. X radiography can reveal changes caused by uranium hydride when it is well established, but scientists need to better understand how corrosion initiates and propagates. Livermore's advanced aging models are used to determine how quickly hydrogen is emitted from various sources inside a weapon.

The corrosion models show the role played by uranium impurities, which, depending on the element, may possibly accelerate formation and growth of uranium hydride. One model, developed by Krishnan Balasubramanian, simulates on an atomic scale how impurities can cause corrosion and how the kinetics of hydrogen liberation are a function of temperature, radiation, and time.




This simulation of an atomic electrical charge shows an atom of uranium next to an atom of tungsten, a contaminant. The close presence of tungsten gives the uranium atom a greater tendency to react with hydrogen and form uranium hydride, which can affect weapon performance.




Postdoctoral researchers Jim Lewicki (background) and Brian Mayer along with chemist Sarah Chinn use nuclear magnetic resonance spectroscopy to investigate key chemical reaction mechanisms responsible for polymer degradation.

## Some Plastics Can Be a Gas

Modern nuclear weapons could not function without hundreds of parts made from polymers, such as foam cushions, O-rings, gaskets, seals, and washers. The parts fill gaps, transmit loads, dampen vibration, and provide cushioning and thermal insulation. Polymers are of particular concern to stockpile scientists because they tend to be reactive. Polymers can change chemically and physically when subjected to radiation, temperature swings, and physical loads. For example, many polymers lose their resiliency over time, potentially allowing components to move about slightly when the weapon is moved.

Chemist Sarah Chinn conducts accelerated aging studies on surplus polymers that were shelved at the same time the weapon entered the stockpile. These tests subject the materials to strong radiation levels and high temperatures. Data from tests are used to refine aging models that help predict changes over the next decade.

Aging studies are particularly important when a polymer must be replaced. “A seemingly simple piece of polymer can have many attributes,” says Chinn. Most polymers have proprietary formulations that a manufacturer can change without notice. “As a result,” she says, “we may obtain a replacement part made by the same manufacturer that produced the part 20 years ago, but the manufacturer has altered its formula. In which case, we must determine the new material’s properties and compatibilities with other polymers. We can’t merely swap the part.”

Chinn is also investigating the possible application of medical diagnostics to enhanced surveillance. For example, radiologists use magnetic resonance imaging to reveal details of soft tissue in humans, but the technology could also be used to detect defects in polymers. Chinn is investigating a nuclear magnetic resonance robotic instrument that could perform nondestructive testing of polymers.

Polymer compatibility is critical to a weapon’s overall state of health. This example shows a sample of the polymer syntactic polysulfide, before (left) and after (right) exposure to an incompatible polymer.

A critical task is examining the gases polymers slowly release during decomposition and material interactions. Indeed, a major issue is potential incompatibilities among polymers. In one compatibility trial, ammonia outgassing by a polymer degraded a nearby component made of a different polymer, turning it into a shapeless blob.

A technique pioneered by Livermore scientists for stockpile stewardship involves solid-phase microextraction (SPME) to analyze organic gases liberated in the head space of nuclear weapons. This technique uses a narrow metal fiber coated with a polymer to adsorb organic compounds. The fiber is inserted into a weapon, and the volatile organic compounds stick to the coated needle. The retrieved needle is then inserted into a gas chromatograph–mass spectrometer to obtain a chemical analysis of a weapon's internal environment. With this technique, hundreds of compounds can be identified at concentrations down to a few parts per billion. In this way, chemists can spot potential material incompatibilities, such as degradation products, synthesis by-products and impurities, and defects such as incompletely cured adhesives. "SPME provides the first clue that a polymer is undergoing change, long before we can see or measure any physical change," says chemist Chris Harvey.

SPME sampling has been performed for a decade on Livermore-designed systems at Pantex. For more extensive analysis, Harvey patented a method to conduct the SPME analysis "offline" in a Pantex laboratory instead of directly on the weapon during disassembly. For this procedure, he adapted a 400-milliliter container to hold gas taken from the weapon. The container is lined with fused silica to prevent organic gases from adsorbing onto the container walls. In the laboratory, operators extract several samples and inject them into a gas chromatograph–mass spectrometer for repeated analyses. According to Harvey, the long-range plan is to build a database of compounds identified by the SPME sampling procedure and connect each compound with its source. In this way, scientists would be able to recognize a compound's likely source the next time it is identified.

The new offline method provides significant time savings, and thereby decreased costs, for SPME sampling. "The process is simple in concept and very beneficial in practice," says Harvey.



(a) The solid-phase microextraction (SPME) technique uses a tiny metal fiber coated with a polymer to adsorb organic compounds liberated in a weapon's headspace. The retrieved needle is inserted into a gas chromatograph–mass spectrometer to obtain a chemical analysis of the weapon's internal environment. (b) For more extensive analysis, chemist Chris Harvey developed a method to conduct SPME "offline" using a 400-milliliter container to hold the gas taken from a warhead. In a laboratory setting, several samples can be extracted for repeated analyses to build a database of compounds.

## Tremendous Progress Made

"We've made tremendous progress over the past 10 years in understanding the aging of our stockpile," says McLean. He compares enhanced surveillance to a careful driver on an unknown road advancing cautiously but guided by powerful headlights to see the way ahead.

Allen notes with satisfaction the strong advances the Laboratory has made in enhanced surveillance and assessing the health of the nation's stockpile. He points out that because Livermore's Enhanced Surveillance Campaign has such a large science component, much of the materials aging work is published in peer-reviewed scientific journals. As a result, the program has helped attract bright, young scientists and engineers to the Laboratory. According to Chinn, "Enhanced surveillance allows next-generation stockpile stewards the opportunity to tackle tough science issues. There are tremendous opportunities to publish and gain exposure beyond our gates."

As the nation gains increased confidence in its nuclear defense, young scientists and engineers are drawn to be future stewards of America's nuclear arsenal and to advance the science of materials. The Stockpile Stewardship Program ensures that the nation's nuclear weapons remain reliable, while developing the science, technology, and knowledge base for the future.

*—Arnie Heller*

**Key Words:** Enhanced Surveillance Campaign, high explosive (HE), life-extension program (LEP), Nuclear Posture Review (NPR), Pantex Plant, photonic Doppler velocimetry (PDV), plutonium, solid-phase microextraction (SPME), Stockpile Stewardship Program, uranium hydride.

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